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Pollutant Concentration in Runoff at McMurdo Station, Antarctica

Rosa T. Affleck, Meredith Carr, Laura Elliot, Corey Chan, and
Margaret Knuth

August 2014

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Pollutant Concentration in Runoff at McMurdo Station, Antarctica

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Final Report

Approved for public release; distribution is unlimited.

Prepared for National Science Foundation, Division of Polar Programs
Antarctic Infrastructure and Logistics
Arlington, VA 22230

Under Engineering for Polar Operations, Logistics, and Research (EPOLAR)
EP-ANT-11-04, "McMurdo Drainage & Erosion Study: 2010-2011 Season"

Abstract

Accidental spills and chemical contamination from leaking fuel and materials (lubricants, paints, etc.) at McMurdo Station have caused environmental concerns, and snowmelt runoff may tend to transport these contaminants. Therefore, the objective of our study was to quantify the pollutant types and levels in the runoff throughout a season. To understand what types of analytes were present and being carried by the runoff into Winter Quarters Bay, we collected water samples from the runoff at major flow arteries at McMurdo Station six times during various flow events in austral summer 2010–2011. Pollutants analyzed included heavy metals, polycyclic aromatic hydrocarbons (PAHs), total hydrocarbons, and volatile organic compounds. Results showed that concentrations for heavy metals were elevated during the first flush when flow began in receiving channels where significant operational or day-to-day activities occurred. In other places, elevated values occurred during the first significant flow; and the concentrations for selected PAHs were elevated during the first peak flow. Given that the snowmelt runoff contained significant concentration of heavy metals and certain PAHs, some of which were above the thresholds for chronic limits for aquatic water quality in saltwater, prevention and mitigation are crucial for reducing contamination at McMurdo Station.

Contents

Abstract	ii
Illustrations	iv
Preface	v
Acronyms and Abbreviations	vi
1 Introduction.....	1
2 Background.....	2
3 Sample Collection and Test Methods	7
3.1 Timing of sampling.....	7
3.2 Test methods.....	8
4 Results	10
4.1 Detection limit.....	10
4.2 Equivalent mass flow rate	11
4.3 Relationship to aquatic life standards.....	14
5 Summary and Conclusion	19
6 Recommendations.....	21
References	23
Appendix A: Procedures for Water Sample Collection during 2010–11 Study	25
Appendix B: Summary of Test Methods and Standards Used and Results of Runoff Water Samples	28
Report Documentation Page	

Illustrations

Figures

1	Map of McMurdo Station showing the watershed boundary (dashed line) and ice field contributing to the snowmelt. The watershed covers an area of approximately 5 km ² (Affleck et al. 2012a)	3
2	McMurdo Station watershed and sub-basin boundaries (Affleck et al. 2012a)	4
3	Along the Gasoline Alley drainage channel adjacent to the fuelling station (photo by Lynette Barna, CRREL, 19 December 2010).....	5
4	Mass flow rate comparison of heavy metals during flow events at channel locations S1, S2C, S3A, S6, and S7	13
5	Mass flow rates of selected polycyclic aromatic hydrocarbons that were above detection limits during flow events at channel locations S1, S2B, S2C, S3A, and S6	14
6	Concentration of heavy metals during flow events at channel locations S1, S2C S3A, S6, and S7. The blue line across the y-axis indicates the chronic limits for saltwater	16
7	Concentration of selected PAHs during flow events at channel locations S1, S2C, S3A, and S6	18

Tables

1	Sampling locations and descriptions.....	7
2	Sampling time and dates for the corresponding flow events.....	8
3	Summary of test methods used and their detection limits	9
4	Pollutant outcome with respect to default detection limits based on Table 3.....	10
5	The corresponding flow rate at each location during the sampling events.....	11
6	Water quality limits on pollutants for aquatic life, published by various agencies. The colors correspond to the limit lines in Figure 6.....	15

Preface

This study was conducted for the National Science Foundation (NSF), Division of Polar Programs (PLR), under Engineering for Polar Operations, Logistics, and Research (EPOLAR) EP-ANT-11-04, "McMurdo Drainage & Erosion Study: 2010–11 Season." The technical monitor was George L. Blaisdell, Chief Program Manager, NSF-PLR, U.S. Antarctic Program.

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At the time of publication, Janet Hardy was the program manager for Engineering for Polar Operations, Logistics, and Research (EPOLAR) Antarctica; Dr. Justin Berman was Chief of the Research and Engineering Division. The Deputy Director of ERDC-CRREL was Dr. Lance Hansen, and the Director was Dr. Robert Davis.

The authors are grateful for the assistance provided by shipping, receiving, supply, and logistics support at McMurdo Station during the field work.

The authors also thank the following CRREL staff for their contributions: Renee Melendy for superb office administrative and logistical support and Joni Quimby for shipping and receiving the equipment and supplies used during the field work.

Emily Moynihan provided our editing support. Technical reviews were provided by Louise Parker (CRREL) and George Blaisdell (National Science Foundation, Division of Polar Programs, Antarctic Infrastructure and Logistics).

The Commander of ERDC is COL Jeffrey R. Eckstein, and the Director of ERDC is Dr. Jeffery P. Holland.

Acronyms and Abbreviations

APHA	American Public Health Association
As	Arsenic
ASCE	American Society of Civil Engineers
BTEX	Benzene, Toluene, Ethylbenzene, and Total Xylenes
CCC	Criterion Continuous Concentration
Cd	Cadmium
CMC	Criteria Maximum Concentration
CPL	Contract Laboratory Program
Co	Cobalt
Cr	Chromium
Cu	Copper
CRREL	Cold Regions Research and Engineering Laboratory
DL	Detection Limit
DNF	Do Not Freeze
EPOLAR	Engineering for Polar Operations, Logistics and Research
ERDC	U.S. Army Engineer Research and Development Center
Fe	Iron
GC-FID	Gas Chromatography–Flame Ionization Detector
GC-MS	Gas Chromatography–Mass Spectrometry
GC-MS FS	Gas Chromatography–Mass Spectrometry with Fused Silica
GC-MS-SIM	Gas Chromatography–Mass Spectrometry with Selective Ion Monitoring

ICP-MS	Inductively Coupled Plasma–Mass Spectrometry
Mn	Manganese
Ni	Nickel
NRDC	National Resources Defense Council
PAHs	Polycyclic Aromatic Hydrocarbons
Pb	Lead
RPSC	Raytheon Polar Services Company
SPE	Solid Phase Extraction
TPHs	Total Petroleum Hydrocarbons
USEPA	U.S. Environmental Protection Agency
WQB	Winter Quarters Bay
VOC	Volatile Organic Compound
Zn	Zinc

1 Introduction

McMurdo Station is a research facility and the logistics hub of the United States Antarctic Program, located on an outcrop of barren volcanic rock on the southern tip of Ross Island, Antarctica. Science support activities at the Station have created some degree of landscape or terrain disturbance and environmental alteration (Klein et al. 2008; Kennicutt et al. 2010). Significant landscape disturbance occurred in the late 1950s and continued in the 1970s as construction activities accommodated expansion. Additionally, accidental spills and chemical contamination from leaking fuel and materials (lubricants, paints, etc.) brought to and used at the Station have caused environmental alterations. Furthermore, the contaminants may have a tendency to be transported in the runoff during the snowmelt period.

Runoff from the watershed is mostly from snowmelt as liquid precipitation is rare at McMurdo. During the austral summer of 2010–11, the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) measured runoff and concentration of pollutants. For the runoff measurements, analyses, and results, see Affleck et al. (2012a, 2014).

The objective of our study was to quantify the pollutant types and levels in the runoff throughout a season. We hypothesized that pollutant levels are likely to be elevated when runoff first begins and will taper as the season progresses. Therefore, this report quantifies the variations in the concentration of pollutants measured during the peak first flush and the subsequent peak runoff events throughout the 2010–11 austral summer season at McMurdo Station. A first flush event is when summer flow starts to trickle with a measureable volume in the channel. A first peak flow normally occurs in early or mid-December, and then subsequent significant flow typically occurs throughout the summer season. Thus we focused our runoff water sampling during the first flush event, the first peak flow, and subsequent high or peak flows throughout the season.

2 Background

Runoff in summer is driven primarily by the melting of snow and glacier ice (Affleck et al. 2012a, 2012b). The major flow paths at McMurdo Station are typically filled with snow and ice in the winter months. As the austral summer approaches, major flow arteries are manually cleared in anticipation of the ephemeral runoff during these summer months. Snowmelt runoff passes through McMurdo via a system of drainage ditches, gullies, and culverts. The major flow paths are well-defined, earthen ditches that cross under the existing roads via culverts (Affleck et al. 2012a). Most of these drainage channels have very steep sides or embankment slopes and steep in-channel gradients. Ultimately, the snowmelt runoff discharges into Winter Quarters Bay (WQB) and McMurdo Sound at several points (Figure 1).

The McMurdo Station watershed is one of the southernmost basins that annually experiences active water flow (Figure 2). The watershed is divided into six basins. Three major sub-basins (1, 2, and 3) are located north of the Station and are largely covered with a perennial snow and glacial cover. The other three sub-basins (5, 6, and 7) are relatively small. Sub-basin 1 drains the area from the west along Hut Point Ridge and Arrival Heights, then along the road and down to the pier and Hut Point. Sub-basin 2 has the largest area and encompasses the majority of the snowfield and the depression above Gasoline Alley. Sub-basin 3 includes the area north of the Main Road, then adjacent to Crater Hill area, loops around portion of the snowfield, and continues on the east at the T-Site area. Snowmelt runoff from sub-basins 2 and 3 merges downstream into WQB. Sub-basin 5 drains the area around the dorm, along the road towards the bay and below the Water Treatment Plant. Sub-basin 6 is composed of the area south of the dorms and Main Road, along the road to the Chalet, and down to the road along the bay. Sub-basin 7 is the area south of the Fuel Tanks, around Observation Hill, and below the Heli Pad.

Figure 1. Map of McMurdo Station showing the watershed boundary (dashed line) and ice field contributing to the snowmelt. The watershed covers an area of approximately 5 km² (Affleck et al. 2012a).

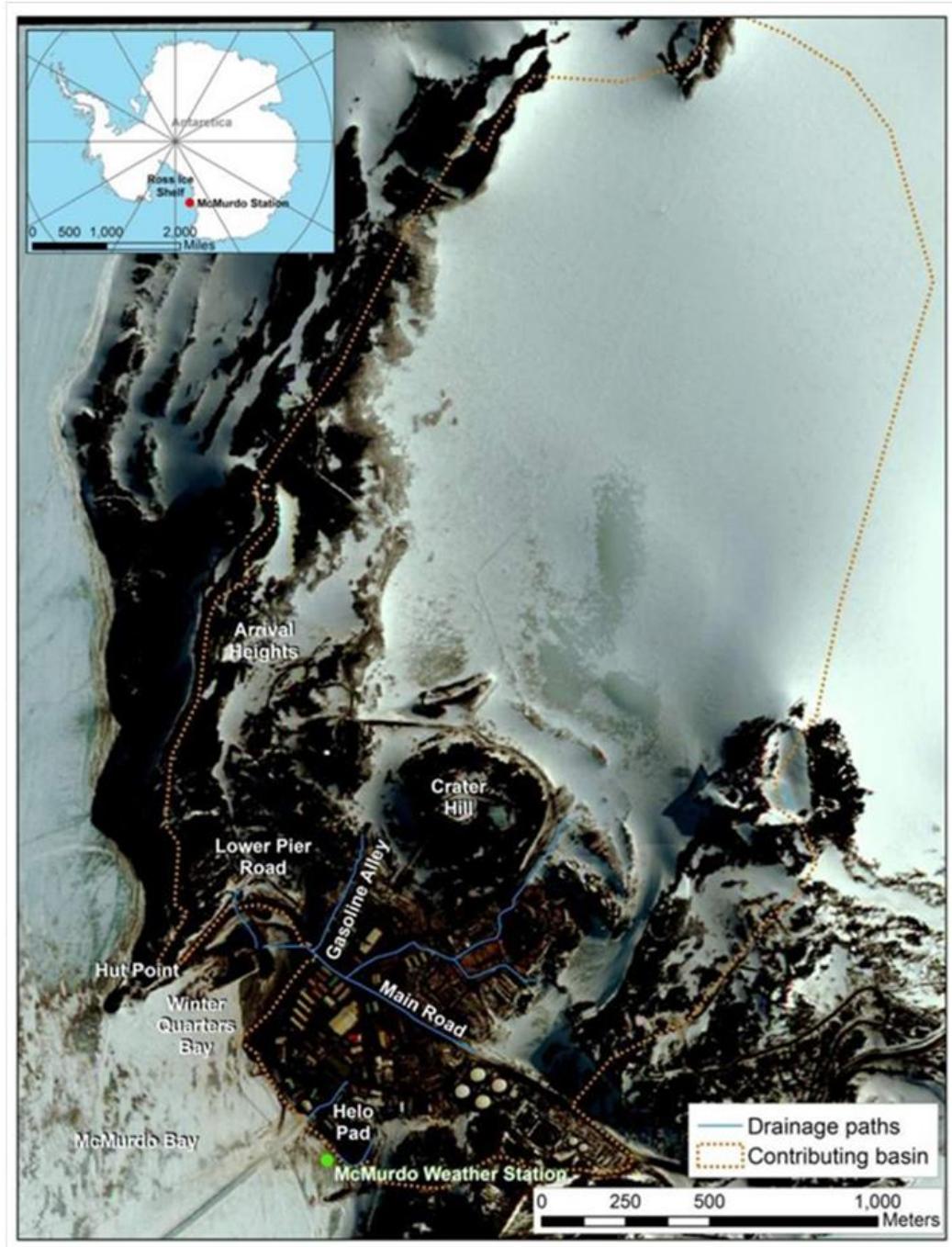


Figure 2. McMurdo Station watershed and sub-basin boundaries (Affleck et al. 2012a).



Some drainage channels intersect areas where vehicles are parked and pass through a fuel pump location (Figure 3). When flow occurs, and especially during these high flow events, soil (particularly soil fines) and contaminants from day-to-day activities or from previous fuel spills move through these drainage paths and out to McMurdo Sound. While studies

done by Kennicutt et al. (2010) and Klein et al. (2008, 2012) have done much to characterize the impacts of human activity at McMurdo Station, they have not quantified the potential movement of pollutants through these drainage paths and flow events throughout a season.

Figure 3. Along the Gasoline Alley drainage channel adjacent to the fuelling station (photo by Lynette Barna, CRREL, 19 December 2010).



The first study to examine how much contamination from fuel spills was being transported by snowmelt runoff in streams around McMurdo Station was done during the 1995–96 and 1996–97 austral summers (Antarctic Support Associates 1997a, 1997b) and showed that significant levels of fuel-related contaminants were picked up by the runoff along the channels, including along Gasoline Alley, by the Heli Pad, and along the Main Road (Figure 1). Although their finding was not from intensive sampling, they indicated that snowmelt runoff transported metals, including arsenic (As), iron (Fe), lead (Pb), manganese (Mn), and zinc (Zn). These metals are naturally leached from soils and, to some degree, from hydrocarbons and other manufactured products. Gasoline, grease, and motor oils are known sources of heavy metals, such as cadmium (Cd), cobalt (Co), copper (Cu), Fe, Mn, nickel (Ni), Pb, and Zn (NRDC 2001). Heavy metals can occur naturally in soils and leach into ground and surface waters but are usually not at toxic levels.

Kennicutt et al. (2010) and Klein et al. (2008, 2012) collected and analyzed several hundred soil samples and over nine years monitored the extent of the environmental impact of the various contaminants. These contaminants were from localized spills and were primarily in the operational active areas at the Station. They found hydrocarbons levels in soils were high in areas where accidental spills occurred and in areas or pads where operational or from day-to-day activities (i.e., vehicle parking, heavy equipment loading and unloading, fueling loading, etc.) were taking place. From 1992 to 2004, up to 10,000 L of localized fuel spills occurred in sub-basins 2 and 3; and 25,000 L of fuel was spilled in sub-basins 6 and 7. Their study found that the total hydrocarbon concentrations in surficial soils at McMurdo Station were dispersed in patches with ranges from 30 to 100 ppm; roads, parking areas, refueling stations, recent fuel spills, the Heli Pad, and the vehicle maintenance facility had the highest concentration of total hydrocarbon (Kennicutt et al. 2010; Klein et al. 2008, 2012).

Crocket (1997) documented the mean background levels of metals present in gray and red soils at McMurdo Station. Both soils' background levels for total metals varied although not very significantly. For example, the gray soil reported to have 5.8 ppm, while the red soil reported to have 5.0 ppm. While Kennicutt et al. (2010) studied heavy metals in contaminated soils, their findings indicated that certain metal concentrations in soil were near background levels and Pb was found to be elevated. Also, they indicated that contamination levels were contained to the areas where spills occurred and that there had been limited redistribution of the contaminants due to limited runoff events. However, Affleck et al. (2012a) found that lateral flows from ice melting in the subsurface (i.e., the active layer) occurred above and along the impermeable frozen soil layer. Thus, contaminants could potentially migrate into the permeable thawed ground and into the drainage channels during runoff.

3 Sample Collection and Test Methods

3.1 Timing of sampling

Timing for water samples collection was essential to the study. Previous snowmelt runoff studies indicated that first flush runoff events occurred around the first week in December. However, the exact timing of these events varied from year to year (Affleck et al. 2012a, 2014). We took several sampling collections at various flow occurrences, including the first flush, first peak, and subsequent peak flow. We defined the first flush event as the first flow incident of the season that had a measureable volume in the channel that could be collected without touching the lip of the wide-mouthed, 1 L glass bottle to the bottom of the ditch. We should note that we expected the flow to peak between 3 pm and 9 pm (Affleck et al. 2012a) under normal conditions. During the first flush and first peak runoff events, we collected two duplicate sample sets at each sample location—one in the morning, prior to the peak flow event, and the other as close to the peak flow event as feasible. We collected the subsequent peak flow water samples to capture contaminant loads as the season progressed. Table 1 describes the water sample locations. We took samples at S1 and S3A at each flow event (Table 2) while, in other locations (i.e., S5 and S6), we took water samples during the first flush only, due to not enough water in the channel. At S2C, we took samples except for during the first flush; this was because the channel still had some ice and did not have enough water to take samples. Appendix A describes our procedures for bottle labeling and handling of water samples.

Table 1. Sampling locations and descriptions.

Locations	Description
S1	Downstream of the culvert by the pier, representing the runoff for sub-basin 1
S2B	Channel along Main Road merging with Gasoline Alley flow, representing the runoff for sub-basins 2 and 3
S2C	Downstream channel along Gasoline Alley, representing the runoff for sub-basin 2
S3A	Channel on Main Road before crossing Gasoline Alley, representing the runoff for sub-basin 3
S5	Flow path developed during the season for sub-basin 5
S6	Above the ditch parallel to the Main Road and an area downstream for sub-basin 6
S7	Downstream of the culvert, Heli Pad, and fuel storage for sub-basin 7

Table 2. Sampling time and dates for the corresponding flow events.

Identifier	Flow Events	Locations	Actual Sampling Dates, Time
1a	First Flush	S1, S2B, S3A, S5, S6, S7	09 Dec. 2010, 4:30–7:40 pm
1b	First Flush Peak	S1, S2B, S3A, S5, S6, S7	09 Dec. 2010, 8:05–9:10 pm
2	First Peak	S1, S2C, S3A, S7	14 Dec. 2010, 7:05–8:40 pm
3	Subsequent Peak	S1, S2C, S3A, S7	29 Dec. 2010, 7:15–8:50 pm
4	Subsequent Peak	S1, S2B, S2C, S3A	17 Jan. 2011, 8:07–9:25 pm
5	Subsequent Peak	S1, S2B, S2C, S3A	21 Jan. 2011, 8:00–9:15 pm

3.2 Test methods

We sent to Hill Laboratories (an environment laboratory in New Zealand) for testing several water samples taken throughout the 2010–11 season. The actual sample dates were 9, 14, and 29 December and 17 and 21 January (Table 2). We collected a total of 70 surface water samples to measure the following:

- Heavy metals, including As, Cd, chromium (Cr), Co, Ni, Pb, and Zn
- Polycyclic aromatic hydrocarbons (PAHs), including acenaphthene, acenaphthylene, anthracene, benzos, chrysene, dibenzo flouranthene, flourene, naphthalene, phenanthrene, pyrene
- Total petroleum hydrocarbons (TPHs) (including C10–C14, C15–C36, and C6–C38) and volatile organic compounds (VOCs), including halogenated aliphatics and monoaromatic hydrocarbons (such as benzene, toluene, ethylbenzene, and total xylenes [i.e., BTEX] compounds).

We shipped to an accredited environmental laboratory, Hill Laboratories in New Zealand, these samples according to sampling and packaging standards and guidance. Hill Laboratories used standard methods (described in this section and summarized in Table 3) to test the samples for the heavy metals, PAHs, TPHs, and VOCs. Samples collected for the heavy metals were tested by Hill Laboratories using inductively coupled plasma–mass spectrometry (ICP-MS) according to U.S. Environmental Protection Agency (USEPA) and the American Public Health Association (APHA) 3125 B (USEPA 1992a). Hill Laboratories tested the PAH samples by using solid phase extraction (SPE) on gas chromatography–mass spectrometry with selective ion monitoring (GC-MS-SIM) instruments and by using the USEPA contract laboratory program (CPL) method. Hill Laboratories extracted and tested samples for TPH by using primarily gas chromatog-

raphy–flame ionization detector (GC-FID) analysis, USEPA method 8015C (USEPA 2007). The lab analyzed VOC samples by using a purge and trap gas chromatography–mass spectrometry with Fused Silica (GC-MS FS) test based on USEPA method 524.2 (USEPA 1992b). Each standard method used to detect the elements and compounds has a default detection limit (Table 3). Appendix B compiles the methods described in this section and the corresponding detection limits for each test.

Table 3. Summary of test methods used and their detection limits.

Test Types	Tests	Methods	Default Detection Limits, $\mu\text{g/L}$ or PPB (g/m^3)
Heavy Metals	Total Arsenic	Nitric acid digestion, ICP-MS, APHA 3125 B 21st ed., USEPA 200.8 (USEPA 1992a)	1.10 (0.0011)
	Total Lead		0.05 (5.3E-5)
	Total Zinc		0.53 (5.3E-4)
	Total Cadmium		
	Total Chromium		
	Total Copper		
Polycyclic Aromatic Hydrocarbons	Total Nickel	Solid Phase Extraction (SPE) if required, GC-MS-SIM analysis, USEPA CPL method (modified)	0.005 (5.0E6)
Total Petroleum Hydrocarbons	C6–C9	Solvent extraction, SPE cleanup, GC-MS analysis (USEPA 2007)	60 (0.060)
	C10–C14	Separating funnel extraction, GC-FID analysis, USEPA 8015C (USEPA 2007)	40 (0.040)
	C15–C36	Separating funnel extraction, GC-FID and purge and trap GC-MS analysis for C6–C9 carbon band (USEPA 2007)	10 (0.01)
	Total hydrocarbons (C6–C36)		200 (0.2)
Volatile Organic Compounds	Listed in Appendix B	Purge and trap GC-MS FS analysis, USEPA Method 524.2 (USEPA 1992b)	Listed in Appendix B

4 Results

4.1 Detection limit

In this analysis, we used the detection limits (DLs) for each of the test methods to determine which contaminants were present in the water samples (Table 4). We found that heavy metals were above the DLs throughout the sampling events and were the most detected pollutants in most channels. Most of the PAHs were below the DL, with the exception of fluoranthene, fluorine, naphthalene, phenanthrene, and Pyrene. This was true for all of the water collected from the S2B, S2C, and S3A channels. We detected TPHs to be above the DL during the first flush and first peak flow events. In contrast, VOCs were all below the detection limit throughout the sampling events. Appendix C presents detailed results for those analytes that exceeded their respective detection level. Values listed with less than the threshold readings (i.e., the < sign with numbers) were considered below the DL).

Table 4. Pollutant outcome with respect to default detection limits based on Table 3.

Tests Locations	Total heavy metals	Polycyclic Aromatic Hydrocarbons	Total Petroleum Hydrocarbons	Volatile Organic Compounds
S1	Above DL except for As and Cd during the first flush	A	Below DL	Below DL
S2B	Above DL	B	C	Below DL
S2C	Above DL	B	D	Below DL
S3A	Above DL	B	C	Below DL
S6	Above DL	A	C	Below DL
S7	Above DL except for As during events 2 and 3	Below DL	Below DL	Below DL

A—Most compounds tested were below the DL except the pyrene compound was above the DL during the first flush.

B—Most compounds tested were below the DL while fluoranthene, fluorene, naphthalene, phenanthrene, and pyrene compounds were above the DL.

C—At the DL during the first flush for C10–C14 and C10–C14 contaminants.

D—At the DL during the first peak flow for C10–C14 and C10–C14 contaminants.

4.2 Equivalent mass flow rate

In conjunction with the pollutant sampling, we measured the discharge from snowmelt for each location during the austral summer of 2010–11, which is documented in Affleck et al (2014). The typical flow in channels at McMurdo Station fluctuates daily and throughout the entire summer season (Affleck et al. 2012a, 2014). As shown in Figure 2, S1 runoff flowed directly into Winter Quarters Bay (WQB). A significant amount of runoff at McMurdo Stations flowed into channels S2C and S3A because both channels received snowmelt runoff from large areas of the watershed (snowmelt runoff from sub-basins 2 and 3). Flow from S2c and S3A merged into S2B, which then diverted into WQB. While S1 and S2B flowed into WQB, flows at S5, S6, and S7 diverted below the Heli Pad. Flows at channels S5, S6, and S7 received snowmelt from small sub-basins in the watershed (Figure 2).

Pressure sensors in the channels where we collected water samples measured stream discharge every 15 minutes (Affleck et al. 2014). Table 5 summarizes the cumulative discharges for the entire day during the corresponding sampling events. Because the runoff varies in each location, we normalized the pollutant concentration to the flow rate for the location sampling time. This provided a mass flow rate estimation (in grams per day) and comparisons between the various sites. We should note that the mass flow rate estimation assumed that the levels of concentration for the analytes were uniform for the corresponding sampling day. We analyzed the mass flow rate primarily for those analytes that were above the DLs at the S1, S2C, S3A, S6, and S7 sites to determine which sub-basins contributed the most pollutant concentration.

Table 5. The corresponding flow rate at each location during the sampling events.

Sampling Events	Sampling Dates	Flow Discharge m ³ /day				
		S1	S2C	S3A	S6	S7
1a and 1b	09 Dec. 2010	1144	832	612	208	840
2	14 Dec. 2010	1261	3489	1507	291	265
3	29 Dec. 2010	953	3508	4239		74
4	17 Jan. 2011	979	1950	2007		
5	21 Jan. 2011	492	2038	1824		

The results showed that the maximum mass flow rate for most heavy metals occurred at site S2C with significant amounts during the first peak flow (event 2); then the amount tapered in the subsequent sampling times later in the season. Within this flow event, these concentrations were approximately 26 g for As, 3.6 g for Cd, 106 g for Cr, 269 g for Cu, 105 g for Pb, 340 g for Ni, and 689 g for Zn all on the same day (i.e., a one-day period) of discharge at S2C. Significant mass flow rates of heavy metals were also transported at the S3A channel, especially during events 1a and 2 and to an extent during event 3. We found Pb to be elevated at S3A during events 1a, 2, and 3. The mass flow rates of metals transported at S2C and S3A were significant, which supported the fact that sub-basins 2 and 3 have large land areas dedicated to operational locations with active day-to-day activities, including cargo storage pads, roads, and parking spaces. When combined, the runoff contained substantial amount of pollutants; for example, the combined amount of Pb discharged to WQB from S1, S2C and S3A was approximately 256 g during the entire day on 14 December 2010. Although significantly smaller in magnitude compared to S2C and S3A, the heavy metals mass flow rates for other locations (S1, S6, and S7, Figure 4) showed an elevated amount when runoff was high; then the amount tapered in the subsequent sampling times later in the season. This was also generally true for site S1.

Similarly, the mass flow rate for selected PAHs, such as acenaphthene, fluoranthene, fluorine, phenanthrene, and pyrene, showed that these contaminants were transported in runoff mostly at S3A and S2C (Figure 5). Phenanthrene was the only PAHs found in the runoff at S1. At S6 and S7, none of these analytes were detected during the sampling periods.

Figure 4. Mass flow rate comparison of heavy metals during flow events at channel locations S1, S2C, S3A, S6, and S7.

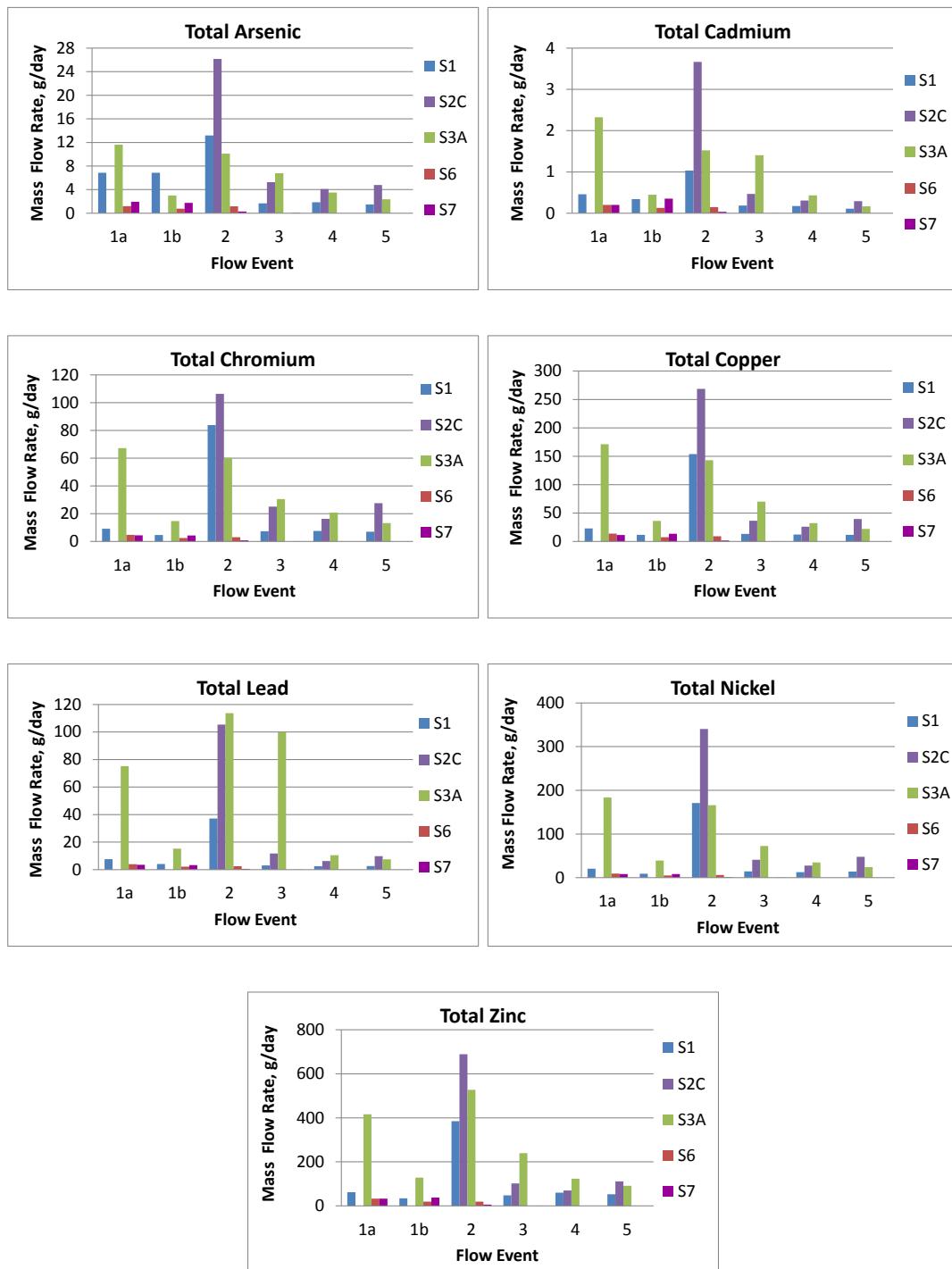
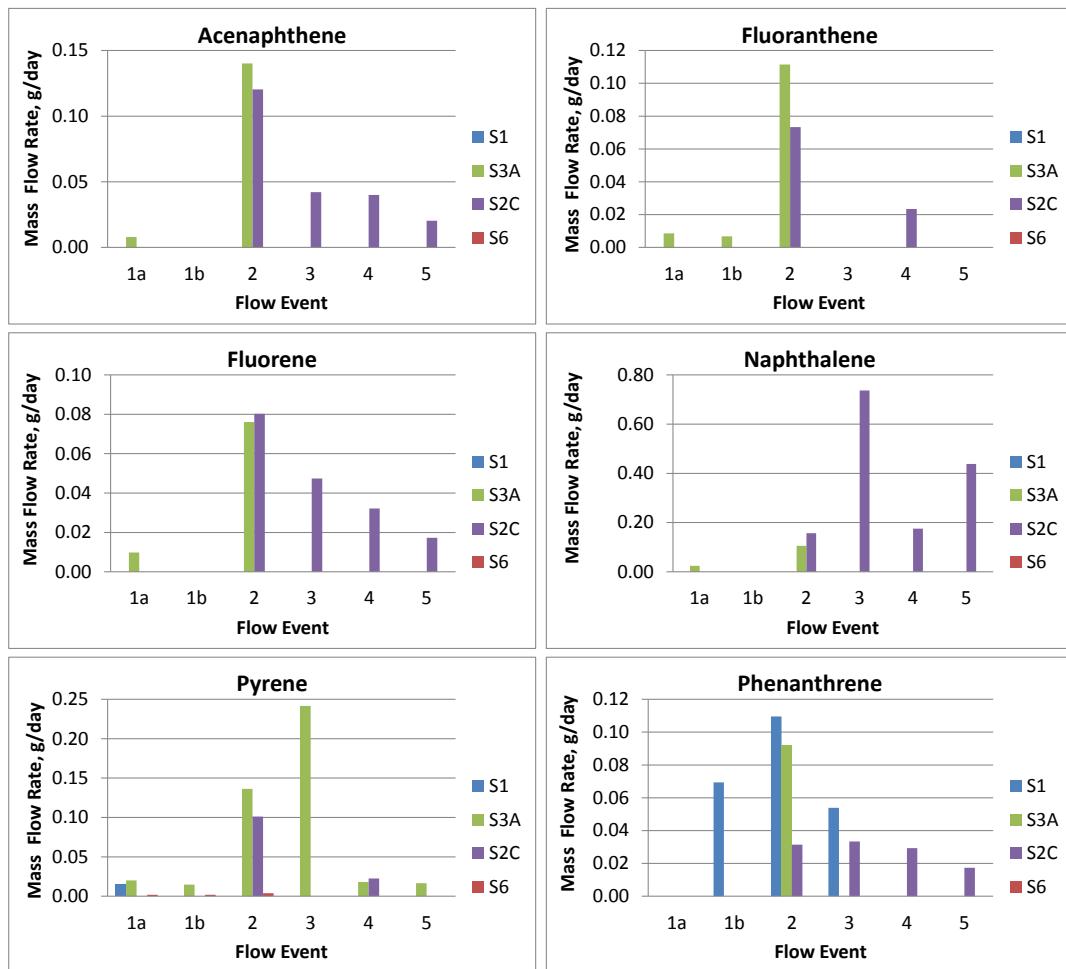


Figure 5. Mass flow rates of selected polycyclic aromatic hydrocarbons that were above detection limits during flow events at channel locations S1, S2B, S2C, S3A, and S6.



4.3 Relationship to aquatic life standards

Because the runoff transported these contaminants into the WQB, we performed analyses to determine which analytes would be of concern for aquatic life. USEPA (2013a) and Nagpal (1995) published criteria on water quality and provided limits for acute and chronic exposures to contaminants for aquatic life. Acute exposure is defined in terms of a criteria maximum concentration (CMC), which is an estimate of the highest concentration of a contaminant in surface water to which an aquatic community can be exposed briefly without an unacceptable effect. Chronic exposure is quantified by a criterion continuous concentration (CCC) value, which is an estimate of the highest concentration of a contaminant in surface water to which an aquatic community can be exposed indefinitely without an un-

acceptable effect. Table 6 gives acute and chronic limits for freshwater and saltwater in order to relate our data. The acute limits for freshwater and saltwater are significantly higher in magnitude than the chronic limits. Our analyses mainly focused on water quality limits for saltwater because McMurdo Sound is part of the Ross Sea.

Table 6. Water quality limits on pollutants for aquatic life, published by various agencies. The colors correspond to the limit lines in Figure 6.

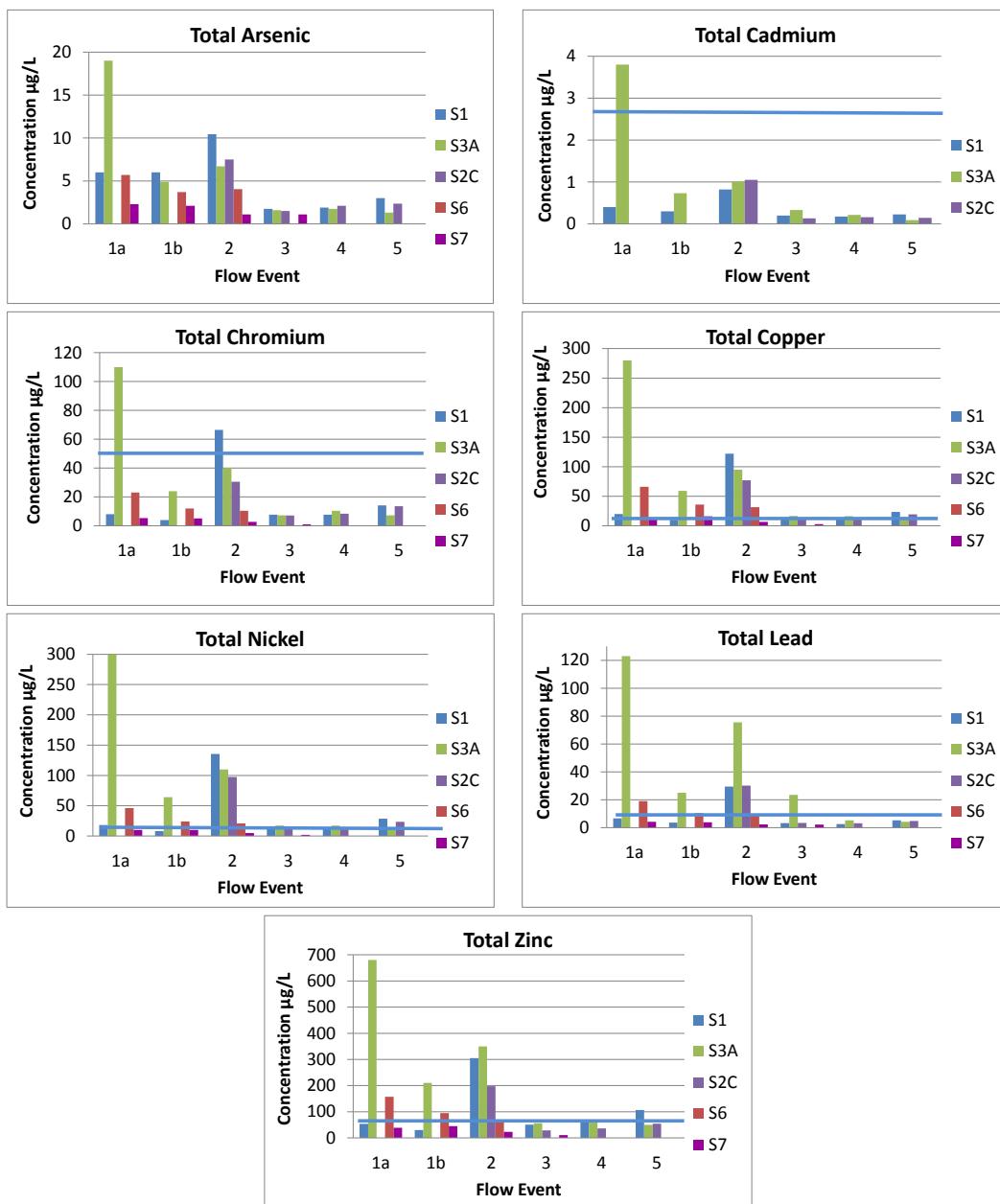
Pollutant	Freshwater		Saltwater	
	CMC (Acute) µg/L	CCC (Chronic) µg/L	CMC (Acute) µg/L	CCC (Chronic) µg/L
Heavy Metals (USEPA 2013)				
Total Arsenic	340	150	69	36
Total Cadmium	2.0	0.25	40	8.8
Total Chromium	16*	11*	1100*	50*
Total Copper	NR	NR	4.8	3.1
Total Lead	65	2.5	210	8.1
Total Nickel	470	52	74	8.2
Total Zinc	120	120	90	81
Polycyclic Aromatic Hydrocarbons (Nagpal 1995)				
Acenaphthene		6		6
Fluoranthene		4		
Fluorene		12		12
Naphthalene		1		1
Phenanthrene		0.3		
Pyrene		NR		NR

* Acute and chronic for Chromium (VI)

NR = no recommendation

Figure 6 shows the concentrations of the various metals during each sampling event. A blue line across the y-axis in Figure 6 illustrates the chronic limits for saltwater (as given in Table 6). The concentrations for heavy metals were elevated during the first flush when flow had just begun at S3A and S6. On the other hand, at the S1 and S2C sites, the concentrations for heavy metals were elevated during the first peak flow (event 2) and declined over time. The concentrations of most heavy metals during flow events at all channel locations were below the acute limits for saltwater. Concentrations for total As were below both acute and chronic limits.

Figure 6. Concentration of heavy metals during flow events at channel locations S1, S2C, S3A, S6, and S7. The blue line across the y-axis indicates the chronic limits for saltwater.



However, the heavy metals that were of most concern with regards to chronic levels for saltwater were Cu, Pb, Ni, and Zn. At several of the sampling locations, concentrations of these metals exceeded the chronic limit for saltwater (Figure 6). The concentration for total Cd and total Cr surpassed the chronic limit during the first flush (events 1a and 1b) in the S3A channel while the concentration of total Cr at S1 exceeded the chronic limit during the first peak flow. Considering that locations S6 and S7 drain from

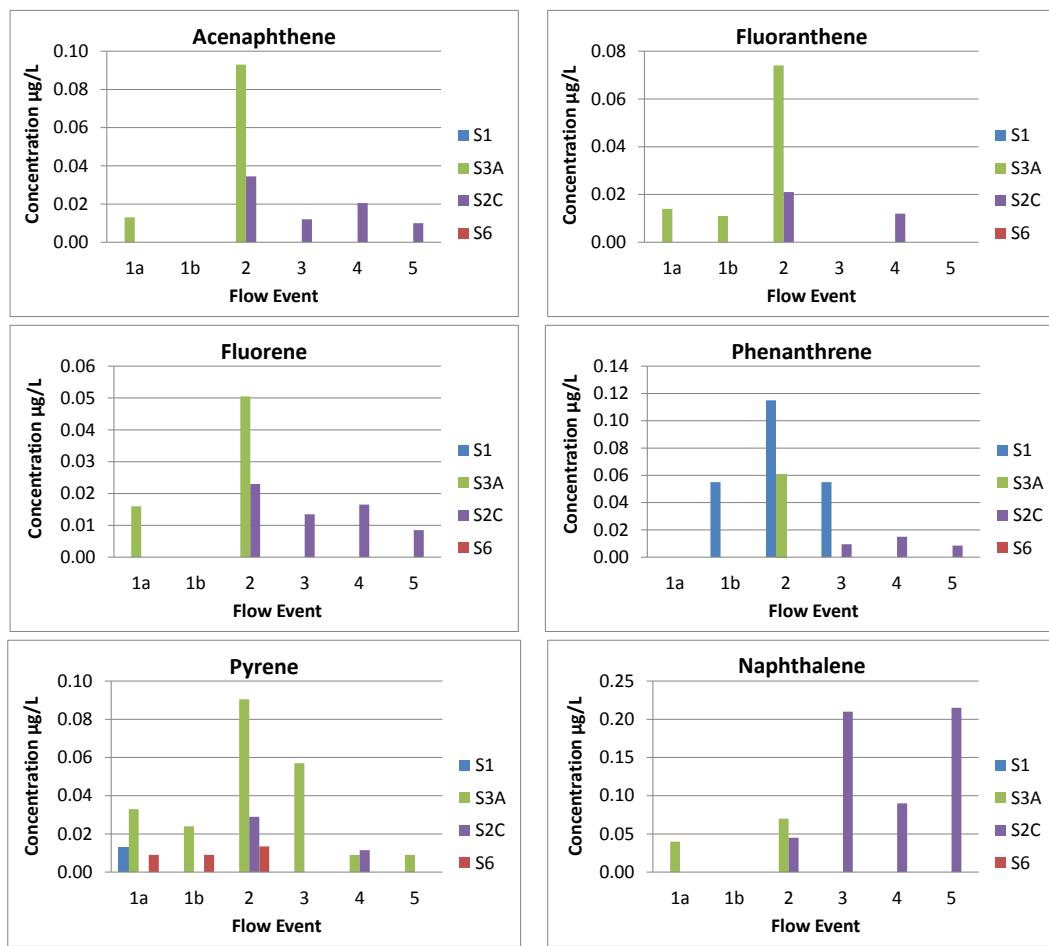
sub-basins with small areas and that concentrations of many of these metals were above the chronic limit, the data revealed that these contaminants exist at levels high enough to be of concern at the Station.

When these analytes are compared to their respective chronic limits for aquatic water quality, Cu was 90 times its limit, Ni was 36 times, and Pb was 15 times when measured at S3A during the first flush alone. During the first peak flow at S2C, the amounts for Cu, Pb and Ni were approximately 25, 4, and 12 times higher than their respective chronic limits. The amount of Cu and Ni discharged above their chronic limits during the entire runoff season in all locations while Pb gradually tapered to below the chronic limit later in the season. The magnitude of the cumulative amounts of these analytes would have staggering environmental impacts. Sources for these pollutants are likely from areas where significant operational or day-to-day activities are performed, including cargo storage, storage pads for materials and for mechanical equipment, and heavy-equipment parking spaces.

We found concentrations above the DLs for several of the PAHs, including acenaphthene, fluoranthene, fluorine, phenanthrene, naphthalene, and pyrene (Figure 7). Concentrations were elevated during the first few sampling events (events 1a through 3) at S3A and at S1 but then decreased during the subsequent flow events. In contrast, at S2C, concentrations of several of these PAHs were elevated during the later sampling events (2, 3, 4, and 5). However, the concentrations of these PAHs were considerably below the published chronic criteria for aquatic life. The maximum concentration values for acenaphthene and naphthalene were 0.093 and 0.215 $\mu\text{g}/\text{L}$ compared to chronic criteria of 6 and 1 $\mu\text{g}/\text{L}$, respectively (Table 6).

Kennicutt et al. (2010) described that most metal concentrations on contaminated soils exceeded the background concentrations at McMurdo reported in Crocket (1997), particularly As, Cd, Co, Pb, and Zn. These contaminated soils were in areas that had previous fuel spills. Thus, we could expect runoff from these areas to also have elevated levels for all or some of these contaminants. Our study suggests that the levels for Cd, Cr, Cu, Pb, Ni, and Zn in the runoff are of concern as they exceeded the chronic limit for aquatic water quality in saltwater.

Figure 7. Concentration of selected PAHs during flow events at channel locations S1, S2C, S3A, and S6.



5 Summary and Conclusion

To understand what types of analytes were present in the runoff and diverted into WQB, we used the limits for water quality to quantify pollutant concentrations. Five times during the 2010–11 austral summer, we sampled for pollutants, including heavy metals, PAHs, total hydrocarbons, and VOCs. The results of this study characterized the concentration levels in the runoff at various locations during the first flush, peak flow of the first flush, and sequential major peak flow events of the season. The overall findings included the following:

- Based on the DL for each test method, heavy metals were present in the water in all of the channels throughout the sampling events.
- The concentrations for heavy metals were elevated at S3A and S6 during the first flush when flow began while, in other places (S1 and S2C), elevated values did not occur until the first significant flow. The concentrations for selected PAHs, such as acenaphthene, fluoranthene, fluorine, phenanthrene, and pyrene, were elevated during the first peak flow at S3A and diminished during the subsequent peak flows later in the season.
- As we compared the analytes to the limits from USEPA (2013a) and Nagpal (1995) for acute and chronic exposure for aquatic life, we found that the analytes of most concern at McMurdo Station included Cd, Cr, Cu, Pb, Ni, and Zn, which exceeded the chronic limit for aquatic water quality (saltwater) in several of the sampling locations. At S3A during the first flush alone, Cu was measured at 90 times the limit, Ni was 36 times, and Pb was 15 times. These contaminants existed in the runoff at the Station at various levels significant enough to be a problem even in the small sub-basins. The magnitude of the cumulative amounts of these analytes could have staggering environmental impacts.
- Overall, S2C and S3A had significant mass flow rates for total heavy metals and for selected PAHs compared to other locations (S1, S2C, S6 and S7). The runoff contained substantial amount of pollutants; for example, the combined amount of Pb discharged to WQB from

S1, S2C and S3A was approximately 256 g during the first peak for the entire day. Both S2C and S3A are composed of large land areas where significant operational or day-to-day activities are performed, including cargo storage, pads where equipment and materials are stored, roads, and parking spaces.

Because temporal flow rate (discharge) in each location varies daily and throughout the season, the pollutant concentration will be high in the beginning of the snowmelt runoff, then fluctuate throughout the entire snowmelt runoff period, and potentially will level off at the end of the summer season. However, a continuous measurement of the pollutant concentration and the total mass discharged for the entire snowmelt runoff can be costly to perform. As the Station's operational activities continue all year round, it is likely that certain levels of pollutants accumulate on the ground and that significant amounts of contaminants are carried out during the first flush event and during early peak flows. This was particularly true in areas with a big operational footprint.

6 Recommendations

Given that the snowmelt runoff contained significant concentration of heavy metals and certain PAHs, prevention and mitigation are crucial for reducing contamination at McMurdo Station. Human factors, such as awareness, cautiousness, improved chemical handling, and environmental friendly practices, can have an important role in reducing contamination. Engineering methods, such as best management practices or erosion control systems (Affleck et al. 2014), can also mitigate further contamination. Erosion control systems are often built to trap sediment and to control or attenuate flow in the receiving channels. These should be used in channels at the Station before the runoff exits into WQB at McMurdo Sound. Given the proper implementation in the unique environment, these systems can improve water quality and can reduce pollutant discharges by allowing these elevated level of contaminations to degrade given time. Other approaches we can pursue include the following:

- Assessment of microbial communities, if present in the runoff, for potential bioremediation
- Evaluation of applicable physical and environmentally-safe chemical treatment technologies to decrease and mitigate the contamination levels
- Assessment of engineering approaches for collecting pollutants on designated vehicle parking areas and at major operational locations.

We recommend a near-term assessment to map out the spatial pattern and levels of previously experienced historical contamination (Kennicutt et al., 2010; Klein et al., 2012) and overlay the existing channel locations. This will aid us in developing a new plan for runoff by finding a better route for drainage away from contaminated areas and by combining several existing flow paths into one primary drainage path. In addition, developing an operational and maintenance toolkit will help facilitate sharing information about existing environmental studies and operational data, which will provide decision making strategies for infrastructure improvements and environmental remediation, when necessary.

The sources of contamination should be dealt with on a case-by-case basis to eliminate the causes of pollution. Elimination of the source is the most efficient way of reducing the effects of pollution migration because dealing with the problem downstream at the final destinations will be more costly and labor intensive for operations.

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Appendix A: Procedures for Water Sample Collection during 2010–11 Study

Raytheon Polar Services Company (RPSC) Environmental staff assisted CRREL in developing and implementing the runoff-sampling portion of the Drainage and Erosion Study for McMurdo Station. What follows is a description of our field sampling methods.

Hill Laboratories (an environment laboratory in New Zealand) provided to RPSC Environmental at McMurdo Station all the bottles and vials used for water samples. Some bottles provided by Hill Laboratories had preservative in the bottles to mix the runoff samples with. Supplies provided by Hill Laboratories included the following:

- 2 × 1 L, wide-mouth glass bottles for sample collection
- 1 × 100 mL polyethylene bottle with nitric acid
- 1 × 500 mL amber glass bottle, unpreserved
- 1 × 250 mL amber glass bottle with sulphuric acid
- 2 × 40 mL amber glass vials with ascorbic acid
- Small red cooler with one blue ice pack to place all the samples collected

We used the sampling procedures as outlined below:

1. Used the designated two 1 L, wide-mouth glass bottles for each sample location to collect the runoff and filled these bottles as much as possible without touching the lip to the bottom of the ditch. Used the water from the two 1-L, wide-mouth glass bottles to fill in the following containers: 100 mL polyethylene bottle with nitric acid preserved; the 500 mL amber glass bottle, unpreserved; 250 mL amber glass bottle with sulphuric acid preserved; and the two 40 mL amber glass vials with ascorbic acid preserved. Item 5 below details transferring the water samples to various bottles.
2. Legibly labeled all samples with the date, time, exact location, and person taking the sample.

3. Used caution with sample bottles that contained preservative and made sure the preservatives were intact and were not overfilled with the water sample.
4. Eliminated to the maximum extent possible potential sources of sample contamination by removing the sample bottle top without touching the inside or the top rim of the bottle and without touching the inside of the bottle-top.
5. Collected and transferred samples.
 - a. Transferred the collected sample to the Hill Laboratories sample bottles, starting with the acid-preserved bottles first and finishing with unpreserved bottles.
 - b. Filled the bottles to within an inch or so of the top without overfilling it (for vials, see #5c and #6 below) and capped each bottle tightly and inverted a few times to mix in the preservative (if applicable).
 - c. Used extra caution when filling the 40 ml vials. **ABSOLUTELY NO AIR BUBBLES, POCKETS, ETC., WERE ALLOWED IN THE VIAL.** Filled the vial slowly until the water reached the mouth. Filled the vial with a few extra drops to allow the water to “mound up” over the lip of the vial (were careful not to overfill the bottle too much since there was acid preservative in it). A tiny amount of overflow was acceptable. Capped the bottle tightly with the Teflon septum provided. To check for bubbles, turned the bottle upside down to see if any bubbles floated up. Tapped the bottle a few times until no bubbles floated up. Otherwise added a few more drops of water into the vial and recapped it tightly. Repeated this process until no bubbles formed.
6. If there was lag time of more than one hour between sample collection locations, returned the sampler to the RPSC Environmental laboratory in Crary to place the sample bottles in a 4°C refrigerator.
7. Immediately after samples were collected, placed them in coolers and chilled them to 4°C with “blue ice.” Placed all samples upright, and secured them in place with inert cushioning, such as bubble wrap or corrugated

cardboard. After proper packaging, prepared the required shipping documents, and coordinated transport of samples to the subcontract laboratory as described below.

8. After each sampling event, made sure to clean the 1 L, wide-mouth sample bottles with a light detergent and water mix and rinsed them with deionized water several times and air dried them to remove all residue from the previous sample collection.

Within 24 to 48 hours, we shipped the filled containers to Hill Laboratories in New Zealand. This required coordination between RPSC Environmental and RPSC Science Cargo for prompt shipment.

To prepare shipment documents, we chose a Transportation Control Number from the logbook, estimated the weight of the samples (recording the exact weight at the time of shipping), and labeled the box or cooler. We indicated special handling of the samples as appropriate (i.e., DNF [do not freeze], Keep Chilled, Time Sensitive, Fragile). The signature of the NSF Representative in the Chalet was required on the retrograde form for COMAIR flights. Once the box was ready, we left it in the staging area and submitted retrograde forms and Ministry of Agriculture and Fisheries permits to the RPSC Science Cargo Coordinator.

Appendix B: Summary of Test Methods and Standards Used and Results of Runoff Water Samples

Table B1 summarizes the test methods used for the runoff samples. The tests included testing for heavy metals, TPHs, and VOCs. Tables B2–B6 list the results from runoff water samples.

Table B1. Methodology and detection limits used for the runoff samples.

SUMMARY OF METHODS		
Sample Type: Surface Water		Page 1 of 3
Test	Method Description	Default Detection Limit
Individual Tests		
Total Digestion	Boiling nitric acid digestion. APHA 3030 E 21 st ed. 2005.	-
Heavy metals, totals, trace As,Cd,Cr,Cu,Ni,Pb,Zn		
Total Arsenic	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21 st ed. 2005 / US EPA 200.8	0.0011 g/m ³
Total Cadmium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21 st ed. 2005 / US EPA 200.8	0.000053 g/m ³
Total Chromium	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21 st ed. 2005 / US EPA 200.8	0.00053 g/m ³
Total Copper	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21 st ed. 2005 / US EPA 200.8	0.00053 g/m ³
Total Lead	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21 st ed. 2005 / US EPA 200.8	0.00011 g/m ³
Total Nickel	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21 st ed. 2005 / US EPA 200.8	0.00053 g/m ³
Total Zinc	Nitric acid digestion, ICP-MS, trace level. APHA 3125 B 21 st ed. 2005 / US EPA 200.8	0.0011 g/m ³
Polycyclic Aromatic Hydrocarbons Trace in Water, By SPE		

Sample Type: Surface Water		Page 2 of 3
Test	Method Description	Default Detection Limit
Acenaphthene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Acenaphthylene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Anthracene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Benzo[a]anthracene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Benzo[a]pyrene (BAP)	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Benzo[b]fluoranthene + Benzo[b]fluoranthene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Benzo[g,h,i]perylene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Benzo[k]fluoranthene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Chrysene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Dibenzo[a,h]anthracene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Fluoranthene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Fluorene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Indeno(1,2,3-c,d)pyrene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Naphthalene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Phenanthrene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Pyrene	Solid phase extraction, SPE (if required), GC-MS SIM analysis. USEPA CLP Method (Modified)	0.000005 g/m ³
Total Petroleum Hydrocarbons in Water 8015		
C6 - C9	Solvent extraction / SPE cleanup / LC-MS analysis. In-house	0.060 g/m ³
C10 - C14	Separating funnel extraction, GC-FID analysis. US EPA 8015C	0.040 g/m ³
C15 - C36	Separating funnel extraction, GC-FID analysis. US EPA 8015C	0.10 g/m ³
Total hydrocarbons (C6 - C36)	Separating funnel extraction, GC-FID and Purge & Trap, GC-MSFS analysis for C6-C9 carbon band.	0.2 g/m ³
Volatile Organic Compounds Trace in Water by Purge&Trap		
Acetone	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.050 g/m ³
Benzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Bromobenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Bromodichloromethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
4-Bromofluorobenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	1.0 %
Bromoform (tribromomethane)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Bromomethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
2-Butanone (MEK)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.0050 g/m ³
n-Butylbenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
tert-Butylbenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Carbon disulphide	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.0050 g/m ³
Carbon tetrachloride	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Chlorobenzene (monochlorobenzene)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Chloroethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Chloroform (Trichloromethane)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Chloromethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
2-Chlorotoluene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
4-Chlorotoluene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,2-Dibromo-3-chloropropane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Dibromochloromethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,2-Dibromoethane (ethylene dibromide, EDB)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00040 g/m ³
Dibromomethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³

Sample Type: Surface Water		Page 3 of 3
Test	Method Description	Default Detection Limit
1,2-Dichlorobenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,3-Dichlorobenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,4-Dichlorobenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Dichlorodifluoromethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,1-Dichloroethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,2-Dichloroethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,1-Dichloroethene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
cis-1,2-Dichloroethene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
trans-1,2-Dichloroethene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Dichlormethane (Methylene chloride)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.010 g/m ³
1,2-Dichloropropane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,3-Dichloropropane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
2,2-Dichloropropane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,1-Dichloropropene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
cis-1,3-Dichloropropene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
trans-1,3-Dichloropropene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Hexachlorobutadiene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Isopropylbenzene (Cumene)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
4-Isopropyltoluene (p-Cymene)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Methyl tert-butylether (MTBE)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.0050 g/m ³
4-Methylpentan-2-one (MIBK)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.0050 g/m ³
Naphthalene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
n-Propylbenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
sec-Butylbenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Styrene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,1,1,2-Tetrachloroethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,1,2,2-Tetrachloroethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Tetrachloroethene (tetrachloroethylene)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Toluene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.0010 g/m ³
Toluene-d8	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	1.0 %
Ethylbenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,2,3-Trichlorobenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,2,4-Trichlorobenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,1,1-Trichloroethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,1,2-Trichloroethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Trichloroethene (trichloroethylene)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Trichlorofluoromethane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,2,3-Trichloropropane	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,1,2-Trichlorotrifluoroethane (Freon 113)	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,2,4-Trimethylbenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
1,3,5-Trimethylbenzene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
Vinyl chloride	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
m&p-Xylene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³
o-Xylene	Purge & Trap, GC-MS FS analysis. USEPA Method 524.2	0.00050 g/m ³

This Laboratory is accredited by International Accreditation New Zealand (IANZ), which represents New Zealand in the International Laboratory Accreditation Cooperation (ILAC). Through the ILAC Mutual Recognition Arrangement (ILAC-MRA) this accreditation is internationally recognised.

Table B2. First Flush outcome at various location, 09 December 2010.

Monoaromatic Hydrocarbons in VOC Water by Purge&Trap GC-MS												
n-Butylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
tert-Butylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Isopropylbenzene (Cumene)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
4-Isopropyltoluene (p-Cymene)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
n-Propylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
sec-Butylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Styrene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,4-Trimethylbenzene	g/m3	< 0.0005	0.0017	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3,5-Trimethylbenzene	g/m3	< 0.0005	0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Ketones in VOC Water by Purge&Trap GC-MS												
Acetone	g/m3	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
2-Butanone (MEK)	g/m3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Methyl tert-butylether (MTBE)	g/m3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
4-Methylpentan-2-one (MBK)	g/m3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Trihalomethanes in VOC Water by Purge&Trap GC-MS												
Bromodichloromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Bromoform (tribromomethane)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chloroform (Trichloromethane)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Dibromochloromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Other VOC in Water by Purge&Trap GC-MS												
Carbon disulphide	g/m3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Naphthalene	g/m3	< 0.0005	0.0011	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	0.0007	< 0.0005	< 0.0005	< 0.0005
System monitoring Compounds for VOC - % Recovery												
4-Bromofluorobenzene	%	101	101	102	106	98	102	98	104	103	101	101
Toluene-d8	%	102	101	100	103	105	99	99	102	102	101	101

Table B3. First Peak Flow of the Season, 14 December 2010.

Event	Local Time	First Peak Flow of the Season, 14-Dec-2010									
		7:05 PM	7:10 PM	7:25 PM	7:30 PM	8:00 PM	8:05 PM	8:20 PM	8:25 PM	8:35 PM	8:40 PM
Location	S3A	S3A-Dup	S2C	S2C-Dup	S1	S1-Dup	S6	S6-Dup	S7	S7-Dup	
Heavy metals, totals, trace As,Cd,Cr,Cu,Ni,Pb,Zn											
Total Arsenic	g/m3	0.0067	0.0067	0.006	0.009	0.0099	0.011	0.0041	0.004	< 0.0011	< 0.0011
Total Cadmium	g/m3	0.00088	0.00114	0.0008	0.0013	0.0008	0.00084	0.00058	0.00044	0.000147	0.000108
Total Chromium	g/m3	0.04	0.04	0.022	0.039	0.065	0.068	0.0111	0.0097	0.0031	0.0024
Total Copper	g/m3	0.084	0.106	0.053	0.101	0.119	0.125	0.033	0.03	0.0071	0.006
Total Lead	g/m3	0.064	0.087	0.0194	0.041	0.029	0.03	0.0092	0.0083	0.0026	0.00199
Total Nickel	g/m3	0.091	0.129	0.065	0.13	0.132	0.139	0.022	0.0194	0.0055	0.0041
Total Zinc	g/m3	0.29	0.41	0.135	0.26	0.3	0.31	0.072	0.063	0.025	0.021
Polycyclic Aromatic Hydrocarbons Trace in Water, By Liq/Liq											
Acenaphthene	g/m3	0.000103	0.000083	0.000033	0.000036	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Acenaphthylene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[a]anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[a]pyrene (BAP)	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[b]fluoranthene + Benzo[j]fluoranthene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[g,h,i]perylene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[k]fluoranthene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Chrysene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Dibeno[a,h]anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Fluoranthene	g/m3	0.000072	0.000076	0.00002	0.000022	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Fluorene	g/m3	0.000052	0.000049	0.000022	0.000024	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Indeno(1,2,3-c,d)pyrene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Naphthalene	g/m3	0.00007	0.00007	0.00004	0.00005	0.00005	0.00006	< 0.00004	< 0.00004	< 0.00004	< 0.00004
Phenanthrene	g/m3	0.000064	0.000058	< 0.000008	0.000009	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Pyrene	g/m3	0.000099	0.000082	0.000026	0.000032	< 0.000008	< 0.000008	0.000014	0.000013	< 0.000008	< 0.000008
Total Petroleum Hydrocarbons in Water 8015											
C6 - C9	g/m3	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
C10 - C14	g/m3	< 0.04	0.04	0.04	0.05	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
C15 - C36	g/m3	< 0.08	< 0.08	0.13	0.13	< 0.08	< 0.08	< 0.08	0.24	< 0.08	< 0.08
Total hydrocarbons (C6 - C36)	g/m3	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.2	< 0.2	< 0.2
BTEX in VOC Water by Purge&Trap GC-MS											
Benzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Toluene	g/m3	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Ethylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
m&p-Xylene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
o-Xylene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005

Monoaromatic Hydrocarbons in VOC Water by Purge&Trap GC-MS											
n-Butylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
tert-Butylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Isopropylbenzene (Cumene)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
4-Isopropyltoluene (p-Cymene)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
n-Propylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
sec-Butylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Styrene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,4-Trimethylbenzene	g/m3	0.0007	0.0006	< 0.0005	0.0008	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3,5-Trimethylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Ketones in VOC Water by Purge&Trap GC-MS											
Acetone	g/m3	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
2-Butanone (MEK)	g/m3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Methyl tert-butylether (MTBE)	g/m3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
4-Methylpentan-2-one (MIBK)	g/m3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Trihalomethanes in VOC Water by Purge&Trap GC-MS											
Bromodichloromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Bromoform (tribromomethane)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chloroform (Trichloromethane)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Dibromochloromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Other VOC in Water by Purge&Trap GC-MS											
Carbon disulphide	g/m3	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Naphthalene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
System monitoring Compounds for VOC - % Recovery											
4-Bromofluorobenzene	%	104	101	109	81	108	103	101	101	101	101
Toluene-d8	%	102	104	102	103	104	102	102	102	103	102

Table B4. Seasonal Peak Flow, 29 December 2010.

Event	Local Time	Peak Flow, 29-Dec-2010							
		7:15 PM		7:20 PM		7:40 PM		8:00 PM	
		S3A	S3A-Dup	S2C	S2C-Dup	S1	S1-Dup	S7	S7-Dup
Heavy metals, totals, trace As,Cd,Cr,Cu,Ni,Pb,Zn	Units:								
Total Arsenic	g/m3	< 0.0011	0.0021	0.0014	0.0016	0.0015	0.002	< 0.0011	< 0.0011
Total Cadmium	g/m3	0.000083	0.00058	0.000132	0.000135	0.000163	0.00023	0.000066	0.00006
Total Chromium	g/m3	0.0032	0.0112	0.0073	0.007	0.0063	0.009	0.00104	0.00107
Total Copper	g/m3	0.0061	0.027	0.0105	0.0103	0.0119	0.0159	0.0027	0.0028
Total Lead	g/m3	0.0061	0.041	0.0034	0.0033	0.0026	0.0039	0.0023	0.0021
Total Nickel	g/m3	0.0063	0.028	0.0119	0.0115	0.0122	0.0178	0.00199	0.002
Total Zinc	g/m3	0.027	0.086	0.03	0.028	0.044	0.057	0.0107	0.0106
Polycyclic Aromatic Hydrocarbons Trace in Water, By Liq/Liq									
Acenaphthene	g/m3	< 0.000008	0.000014	0.000011	0.000013	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Acenaphthylene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[a]anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[a]pyrene (BAP)	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[b]fluoranthene + Benzo[j]fluoranthene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[g,h,i]perylene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[k]fluoranthene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Chrysene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Dibenz[a,h]anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Fluoranthene	g/m3	< 0.000008	0.00002	< 0.000008	0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Fluorene	g/m3	< 0.000008	< 0.000008	0.000013	0.000014	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Indeno(1,2,3-c,d)pyrene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Naphthalene	g/m3	< 0.00004	< 0.00004	0.0002	0.00022	0.00013	0.0001	< 0.00004	< 0.00004
Phenanthrene	g/m3	< 0.000008	< 0.000008	0.000009	0.00001	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Pyrene	g/m3	0.000016	0.000098	< 0.000008	0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Total Petroleum Hydrocarbons in Water 8015									
C6 - C9	g/m3	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
C10 - C14	g/m3	< 0.04	0.05	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
C15 - C36	g/m3	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08
Total hydrocarbons (C6 - C36)	g/m3	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
BTEX in VOC Water by Purge&Trap GC-MS									
Benzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Toluene	g/m3	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Ethylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
m&p-Xylene	g/m3	< 0.0005	< 0.0005	0.0009	0.0008	< 0.0005	< 0.0005	< 0.0005	< 0.0005
o-Xylene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005

Halogenated Aliphatics in VOC Water by Purge&Trap GC-MS									
Bromomethane	g/m3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Carbon tetrachloride	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chloromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dibromo-3-chloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dibromoethane (ethylene dibromide, EDB)	g/m3	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004
Dibromomethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Dichlorodifluoromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1-Dichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1-Dichloroethene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
cis-1,2-Dichloroethene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
trans-1,2-Dichloroethene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Dichloromethane (methylene chloride)	g/m3	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
1,2-Dichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3-Dichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
2,2-Dichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1-Dichloropropene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
cis-1,3-Dichloropropene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
trans-1,3-Dichloropropene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Hexachlorobutadiene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,1,2-Tetrachloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,2,2-Tetrachloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Tetrachloroethene (tetrachloroethylene)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,1-Trichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,2-Trichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Trichloroethene (trichloroethylene)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Trichlorofluoromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,3-Trichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,2-Trichlorotrifluoroethane (Freon 113)	g/m3	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Vinyl chloride	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005

Halogenated Aromatics in VOC Water by Purge&Trap GC-MS									
Bromobenzene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chlorobenzene (monochlorobenzene)	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
2-Chlorotoluene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
4-Chlorotoluene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dichlorobenzene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3-Dichlorobenzene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,4-Dichlorobenzene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,3-Trichlorobenzene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,4-Trichlorobenzene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3,5-Trichlorobenzene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Monoaromatic Hydrocarbons in VOC Water by Purge&Trap GC-MS									
n-Butylbenzene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
tert-Butylbenzene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Isopropylbenzene (Cumene)	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
4-Isopropyltoluene (p-Cymene)	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
n-Propylbenzene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
sec-Butylbenzene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Styrene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,4-Trimethylbenzene	g/m ³	< 0.0005	< 0.0005	0.0019	0.0017	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3,5-Trimethylbenzene	g/m ³	< 0.0005	< 0.0005	0.0009	0.0008	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Ketones in VOC Water by Purge&Trap GC-MS									
Acetone	g/m ³	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
2-Butanone (MEK)	g/m ³	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Methyl tert-butylether (MTBE)	g/m ³	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
4-Methylpentan-2-one (MIBK)	g/m ³	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Trihalomethanes in VOC Water by Purge&Trap GC-MS									
Bromodichloromethane	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Bromoform (tribromomethane)	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chloroform (Trichloromethane)	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Dibromochloromethane	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Other VOC in Water by Purge&Trap GC-MS									
Carbon disulphide	g/m ³	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Naphthalene	g/m ³	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
System monitoring Compounds for VOC - % Recovery									
4-Bromofluorobenzene	%	94	93	94	95	92	94	92	95
Toluene-d8	%	96	88	93	105	92	93	88	90

Table B5. Seasonal Peak Flow, 17 January 2010.

Event	Local Time	Peak Flow, 17-Jan-2011							
		S3A		S3A-Dup		S2C		S2C-Dup	
		S2B	S2B-Dup	S1	S1-Dup				
Heavy metals, totals, trace As,Cd,Cr,Cu,Ni,Pb,Zn	Units:								
Total Arsenic	g/m3	0.0016	0.0019	0.0022	0.002	0.0016	0.0019	0.0019	0.0019
Total Cadmium	g/m3	0.00022	0.00021	0.000174	0.000143	0.000164	0.000171	0.000182	0.000171
Total Chromium	g/m3	0.0104	0.0103	0.0088	0.0079	0.0081	0.0089	0.0079	0.0075
Total Copper	g/m3	0.0162	0.0161	0.0133	0.0134	0.0163	0.0131	0.0123	0.0124
Total Lead	g/m3	0.0052	0.0052	0.0033	0.0031	0.0039	0.0071	0.0026	0.0026
Total Nickel	g/m3	0.0171	0.0175	0.0143	0.014	0.0147	0.0142	0.0124	0.0131
Total Zinc	g/m3	0.062	0.061	0.037	0.035	0.051	0.05	0.06	0.062
Polycyclic Aromatic Hydrocarbons Trace in Water, By Liq/Liq									
Acenaphthene	g/m3	< 0.000008	< 0.000008	0.00002	0.000021	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Acenaphthylene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benz[a]anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benz[a]pyrene (BAP)	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benz[b]fluoranthene + Benzo[j]fluoranthene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[g,h,i]perylene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[k]fluoranthene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Chrysene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Dibenz[a,h]anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Fluoranthene	g/m3	< 0.000008	< 0.000008	0.000012	0.000012	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Fluorene	g/m3	< 0.000008	< 0.000008	0.000016	0.000017	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Indeno(1,2,3-c,d)pyrene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Naphthalene	g/m3	< 0.00004	< 0.00004	0.00009	0.00009	< 0.00004	< 0.00004	0.00005	0.00006
Phenanthrene	g/m3	< 0.000008	< 0.000008	0.000015	0.000015	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Pyrene	g/m3	< 0.000008	0.000009	0.000011	0.000012	0.000012	0.000012	< 0.000008	< 0.000008
Total Petroleum Hydrocarbons in Water 8015									
C6 - C9	g/m3	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
C10 - C14	g/m3	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	0.05
C15 - C36	g/m3	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08
Total hydrocarbons (C6 - C36)	g/m3	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
BTEX in VOC Water by Purge&Trap GC-MS									
Benzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Toluene	g/m3	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Ethylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
m&p-Xylene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
o-Xylene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005

Halogenated Aliphatics in VOC Water by Purge&Trap GC-MS									
Bromomethane	g/m3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Carbon tetrachloride	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chloromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dibromo-3-chloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dibromoethane (ethylene dibromide, EDB)	g/m3	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004
Dibromomethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Dichlorodifluoromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1-Dichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1-Dichloroethene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
cis-1,2-Dichloroethene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
trans-1,2-Dichloroethene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Dichloromethane (methylene chloride)	g/m3	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
1,2-Dichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3-Dichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
2,2-Dichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1-Dichloropropene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
cis-1,3-Dichloropropene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
trans-1,3-Dichloropropene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Hexachlorobutadiene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,1,2-Tetrachloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,2,2-Tetrachloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Tetrachloroethene (tetrachloroethylene)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,1-Trichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,2-Trichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Trichloroethene (trichloroethylene)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Trichlorofluoromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,3-Trichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,2-Trichlorotrifluoroethane (Freon 113)	g/m3	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Vinyl chloride	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005

Halogenated Aromatics in VOC Water by Purge&Trap GC-MS									
Bromobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chlorobenzene (monochlorobenzene)	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
2-Chlorotoluene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
4-Chlorotoluene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3-Dichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,4-Dichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,3-Trichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,4-Trichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3,5-Trichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Monoaromatic Hydrocarbons in VOC Water by Purge&Trap GC-MS									
n-Butylbenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
tert-Butylbenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Isopropylbenzene (Cumene)	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
4-Isopropyltoluene (p-Cymene)	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
n-Propylbenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
sec-Butylbenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Styrene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,4-Trimethylbenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3,5-Trimethylbenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Ketones in VOC Water by Purge&Trap GC-MS									
Acetone	g/m ₃	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
2-Butanone (MEK)	g/m ₃	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Methyl tert-butylether (MTBE)	g/m ₃	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
4-Methylpentan-2-one (MIBK)	g/m ₃	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Trihalomethanes in VOC Water by Purge&Trap GC-MS									
Bromodichloromethane	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Bromoform (tribromomethane)	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chloroform (Trichloromethane)	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Dibromochloromethane	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Other VOC in Water by Purge&Trap GC-MS									
Carbon disulphide	g/m ₃	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Naphthalene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
System monitoring Compounds for VOC - % Recovery									
4-Bromofluorobenzene	%	99	98	97	97	96	97	96	98
Toluene-d8	%	100	101	100	101	102	101	96	102

Table B6. Seasonal Peak Flow, 21 January 2010.

Event	Local Time	Peak Flow, 21-Jan-2011							
		8:00 PM	8:07 PM	8:25 PM	8:30 PM	8:40 PM	8:45 PM	9:00 PM	9:15 PM
Location	S3A	S3A-Dup	S2C	S2C-Dup	S2B	S2B-Dup	S1	S1-Dup	
Heavy metals, totals, trace As,Cd,Cr,Cu,Ni,Pb,Zn	Units:								
Total Arsenic	g/m3	0.0014	0.0012	0.0023	0.0024	0.0017	0.0013	0.003	0.003
Total Cadmium	g/m3	0.000088	0.000093	0.000168	0.000119	0.000101	0.000118	0.000179	0.00027
Total Chromium	g/m3	0.0073	0.0072	0.0134	0.0137	0.0087	0.0073	0.0127	0.0156
Total Copper	g/m3	0.0122	0.012	0.0194	0.0192	0.0132	0.0117	0.021	0.026
Total Lead	g/m3	0.0043	0.004	0.0048	0.0048	0.0042	0.004	0.0046	0.0058
Total Nickel	g/m3	0.0134	0.013	0.023	0.024	0.0153	0.0134	0.025	0.032
Total Zinc	g/m3	0.05	0.05	0.055	0.054	0.054	0.046	0.098	0.116
Polycyclic Aromatic Hydrocarbons Trace in Water, By Liq/Liq									
Acenaphthene	g/m3	< 0.000008	< 0.000008	0.00001	0.00001	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Acenaphthylene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benz[a]anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benz[a]pyrene (BAP)	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benz[b]fluoranthene + Benzo[j]fluoranthene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[g,h,i]perylene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Benzo[k]fluoranthene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Chrysene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Dibenz[a,h]anthracene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Fluoranthene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Fluorene	g/m3	< 0.000008	< 0.000008	0.000009	0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Indeno(1,2,3-c,d)pyrene	g/m3	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Naphthalene	g/m3	< 0.00004	< 0.00004	0.00024	0.00019	< 0.00004	< 0.00004	< 0.00004	< 0.00004
Phenanthrene	g/m3	< 0.000008	< 0.000008	0.000008	0.000009	< 0.000008	< 0.000008	< 0.000008	< 0.000008
Pyrene	g/m3	0.00001	0.000008	< 0.000008	< 0.000008	0.000009	0.000009	< 0.000008	< 0.000008
Total Petroleum Hydrocarbons in Water 8015									
C6 - C9	g/m3	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
C10 - C14	g/m3	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04	< 0.04
C15 - C36	g/m3	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08	< 0.08
Total hydrocarbons (C6 - C36)	g/m3	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
BTEX in VOC Water by Purge&Trap GC-MS									
Benzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Toluene	g/m3	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010	< 0.0010
Ethylbenzene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
m&p-Xylene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
o-Xylene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005

Halogenated Aliphatics in VOC Water by Purge&Trap GC-MS									
Bromomethane	g/m3	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Carbon tetrachloride	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chloromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dibromo-3-chloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dibromoethane (ethylene dibromide, EDB)	g/m3	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004
Dibromomethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Dichlorodifluoromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1-Dichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1-Dichloroethene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
cis-1,2-Dichloroethene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
trans-1,2-Dichloroethene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Dichloromethane (methylene chloride)	g/m3	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
1,2-Dichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3-Dichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
2,2-Dichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1-Dichloropropene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
cis-1,3-Dichloropropene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
trans-1,3-Dichloropropene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Hexachlorobutadiene	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,1,2-Tetrachloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,2,2-Tetrachloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Tetrachloroethene (tetrachloroethylene)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,1-Trichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,2-Trichloroethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Trichloroethene (trichloroethylene)	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Trichlorofluoromethane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,3-Trichloropropane	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,1,2-Trichlorotrifluoroethane (Freon 113)	g/m3	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
Vinyl chloride	g/m3	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005

Halogenated Aromatics in VOC Water by Purge&Trap GC-MS									
Bromobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chlorobenzene (monochlorobenzene)	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
2-Chlorotoluene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
4-Chlorotoluene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2-Dichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3-Dichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,4-Dichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,3-Trichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,4-Trichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,3,5-Trichlorobenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Monoaromatic Hydrocarbons in VOC Water by Purge&Trap GC-MS									
n-Butylbenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
tert-Butylbenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Isopropylbenzene (Cumene)	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
4-Isopropyltoluene (p-Cymene)	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
n-Propylbenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
sec-Butylbenzene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Styrene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
1,2,4-Trimethylbenzene	g/m ₃	< 0.0005	< 0.0005	0.0013	0.0012	0.0005	< 0.0005	< 0.0005	< 0.0005
1,3,5-Trimethylbenzene	g/m ₃	< 0.0005	< 0.0005	0.0006	0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Ketones in VOC Water by Purge&Trap GC-MS									
Acetone	g/m ₃	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
2-Butanone (MEK)	g/m ₃	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Methyl tert-butylether (MTBE)	g/m ₃	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
4-Methylpentan-2-one (MIBK)	g/m ₃	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Trihalomethanes in VOC Water by Purge&Trap GC-MS									
Bromodichloromethane	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Bromoform (tribromomethane)	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Chloroform (Trichloromethane)	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Dibromochloromethane	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
Other VOC in Water by Purge&Trap GC-MS									
Carbon disulphide	g/m ₃	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Naphthalene	g/m ₃	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
System monitoring Compounds for VOC - % Recovery									
4-Bromofluorobenzene	%	95	95	95	95	96	96	94	93
Toluene-d8	%	99	100	99	100	98	99	98	98

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE (DD-MM-YYYY) 25-08-2014			2. REPORT TYPE Technical Report/Final		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Pollutant Concentration in Runoff at McMurdo Station, Antarctica					5a. CONTRACT NUMBER	
					5b. GRANT NUMBER	
					5c. PROGRAM ELEMENT	
6. AUTHOR(S) Rosa T. Affleck , Meredith Carr , Laura Elliot , Corey Chan , and Margaret Knuth					5d. PROJECT NUMBER	
					5e. TASK NUMBER EP-ANT-11-04	
					5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Engineer Research and Development Center (ERDC) Cold Regions Research and Engineering Laboratory (CRREL) 72 Lyme Road, Hanover, NH 03755-1290					8. PERFORMING ORGANIZATION REPORT NUMBER ERDC/CRREL TR-14-15	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Science Foundation, Division of Polar Programs Antarctic Infrastructure and Logistics Arlington, VA 22230					10. SPONSOR/MONITOR'S ACRONYM(S) NSF	
					11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.						
13. SUPPLEMENTARY NOTES Engineering for Polar Operations, Logistics, and Research (EPOLAR)						
14. ABSTRACT Accidental spills and chemical contamination from leaking fuel and materials (lubricants, paints, etc.) at McMurdo Station have caused environmental concerns, and snowmelt runoff may tend to transport these contaminants. Therefore, the objective of our study was to quantify the pollutant types and levels in the runoff throughout a season. To understand what types of analytes were present and being carried by the runoff into Winter Quarters Bay, we collected water samples from the runoff at major flow arteries at McMurdo Station six times during various flow events in austral summer 2010–2011. Pollutants analyzed included heavy metals, polycyclic aromatic hydrocarbons (PAHs), total hydrocarbons, and volatile organic compounds. Results showed that concentrations for heavy metals were elevated during the first flush when flow began in receiving channels where significant operational or day-to-day activities occurred. In other places, elevated values occurred during the first significant flow; and the concentrations for selected PAHs were elevated during the first peak flow. Given that the snowmelt runoff contained significant concentration of heavy metals and certain PAHs, some of which were above the thresholds for chronic limits for aquatic water quality in saltwater, prevention and mitigation are crucial for reducing contamination at McMurdo Station.						
15. SUBJECT TERMS Contaminants, drainage, EPOLAR, erosion, heavy metals, hydrocarbons, NSF, snowmelt						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 56	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (include area code)	